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## (54) VAPOUR SATURATED GAS DELIVERY

(71) I, GRAHAM CAMERON GRANT, of 16/49, Campbell Parade, Manly Vale 2093 in the State of New South Wales, Commonwealth of Australia; an Australian Citizen, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the delivery of gases to a delivery point at a predetermined temperature and at a predetermined humidity. It has particular application in relation to medical humidifiers, as herein described, but it is also applicable to other type of humidifiers.

When a person breathes, his air passages are normally capable of supplying the appropriate amounts of heat and moisture to the inhaled gases. However, under certain conditions encountered in medical practice a patient's mechanism for supplying heat and moisture to inhaled gas is interfered with, and it becomes necessary to condition the gas supplied to the patient artificially. The patients for whom administration of artifically conditioned gas may be indicated include shocked or very ill patients, patients whose air passagges have been bypassed by a tube or tracheostomy for artificial ventilation, neonatal patients (who have a low reserve of heat and moisture) under-going intensive care, and patients who are subjected to prolonged breathing of cylinder-stored compressed gases. Proper conditioning of the gas to be supplied to each patient involves heating it to a temperature at or near normal body temperature (37°C) and humidifying it to a level at or near 100% saturation.

Apparatus which is currently employed for the conditioning of gases to be delivered to a patient generally takes the form of either a nebuliser or a heated humidifier. Nebulisers produce a suspension of fine water droplets by atomisation but they are noisy in operation and they are prone to failure as a result of jet blockage. It is therefore preferable to use heated humidifiers which supply heat and moisture to a gas by passage through or over a heated waterbath or evaporative surface and it is to heated humidifiers that the present invention is applicable.

Currently available kinds of heated humidifiers are either simple humidifiers or are heated-hose humidifiers, but each kind has its characteristic disadvantages. In simple humidifiers, gases are passed over heated water within a humidification tank and are then passed to a patient by way of a flexible hose. Considerable heat losses to atmosphere occur during passage of the gas through the hose and, in order to obtain a delivery temperature at or near body temperature it is necessary to heat the water in the humidification tank to a temperature significantly higher than body temperature, with the result that there is heavy condensation along the hose length. Unless the condensate is cleared from the system a potentially hazardous situation may be created. In known designs of heated hose humidifiers, formation of condensation in the delivery hose is avoided by heating the delivery hose so as to maintain the gases therein at a constant temperature. However, in such designs the humidification tank itself has been run at or near normal body temperature so as to supply gas at 100% relative humidity to the delivery hose, and such designs have required a much larger than normal evaporative surface because a simple humidification tank will not produce vapour at above approximately 80% saturation at the gas flows involved. The designs of humidification tank required have been complicated and difficult to service and clean.

An object of this invention is the provision of an improved method and apparatus for providing gases to a delivery point at a required temperature and with a desired humidity, which in the case of a medical humidifier will be about normal body temperature and about 100% relative humidity.

In one aspect the invention provides a method for delivery of warm humidified gas to a delivery point, comprising:

heating the gas to a temperature $T_1$ and to a percentage saturation level $W_1$ of less than 100% saturation; and

transferring the gas to a delivery point via a delivery line, sensing the temperature of the gas at the delivery point end of the delivery line by means of a sensor, and controlling the temperature of the gas in the delivery line in accordance with signals from said sensor to prevent condensation from forming in the delivery line and to provide for a lower temperature $T_2$ which corresponds with a selected higher percentage saturation level $W_2$ at the delivery point.

The method of the invention is based on the realization that the problems associated with heated-hose humidifiers can be overcome if the gas leaving the humidification tank is less than 100% saturated and is allowed to cool during its passage through the delivery hose with supply of an amount of heat controlled in accordance with the perceived temperature of the gas at the delivery point end of the delivery hose so as to prevent condensation in the delivery hose and so that the gas reaches the delivery point at the appropriate temperature and at or near 100% saturation.

In another aspect the invention provides an apparatus for delivering humidified gas at a desired temperature to a delivery point comprising:

a humidification chamber for supplying warm humidified gas and having an inlet port for gas to be humidified and an outlet port for the warm humidified gas;

a delivery line between the outlet of the humidification chamber and the delivery point;

a temperature sensor at the delivery point end of the delivery line for providing a signal significant of the delivered gas temperature; and

heating means for preventing condensation from forming in the delivery line and for maintaining the temperature of the gas supplied to the delivery point at the desired value, and including an electrical resistance heater provided along the delivery line and whose heat dissipation is controlled independently of the temperature of the liquid in the humidification chamber by means of a first temperature controller responsive to the signal from the temperature sensor.

The invention as above defined contrasts with the prior art designs of heated-hose humidifier which have operated on the principle of saturating the gas at the humidification stage to the percentage saturation level and temperature required at the delivery point and then passing the humidified gas through a delivery line held at that temperature. The disadvantage with such a system in practice is that changes in the gas flow rate and in ambient temperature conditions produce corresponding changes in temperature and humidity of the gas leaving the humidifier and entering the delivery line. The temperature difference between the delivery line and the humidifier can produce condensation in the line if the former is held beneath the temporary operating temperature of the latter. This risk cannot be tolerated and is avoided by the Applicant's invention which teaches that the line temperature must be controlled — not simply stabilised.

The temperature sensor conveniently comprises a sensing element located at the patient end of the delivery line and it is preferably located in the gas stream. The heat applied to the gas passing through the dlivery line is regulated in response to the temperature sensed by the sensor to provide the desired temperature at the delivery point. This permits the use of a simple design of humidification tank and initial heating of the gas to a temperature above normal body temperature which is that required at the delivery point. The humidification tank does not itself need to produce full saturation but instead full saturation without condensation is achieved by allowing for a temperature drop along the delivery line.

A simple design of humdification tank may give varying degrees of saturation with changes in gas flow through the apparatus, the delivery point temperature being maintained constant. However any such variation is unimportant in practice because the apparatus of the invention can deliver humidified gas to a patient at or near 100% saturation over a wide range of flow rates, and the actual percentage saturation is not believed to be critical from the point of view of the patient's well being provided that it is near 100%.

The invention has particular application to the delivery of air or oxygen to a patient. The temperature control of the gas in the delivery line may be effected by means of heating element (e.g. an electrical resistance type heating element) located within or about the delivery line and extending substantially the whole length thereof.

In the interest of convenienne and economics, it is desirable that the same humidifier should be suitable for both adult and paediatrics use, and to meet this requirement the following criteria must be satisfied:

a) For adults, the area of the evaporaive surface in the humidification chamber must be large enough to produce a high level of humidity at high gas flow rates, and the capacity of the chamber for water must be sufficiently large to avoid the need for frequent refilling.

b) For infants, the compression volume of the humidification chamber should be as small as possible so as to minimise the compliance of the patient circuit.

A simple humidification cannot simuitaeously meet these two seemingly conflicting requirements. However, these problems can be overcome by having a water reservoir separated from the humidification chamber, and maintaining a constant water level within the humidification chamber by supplying it with water from the reservoir as and when required. The humidification chamber can then be kept quite small to preserve a low compression volume. However, if there is direct communication between the reservoir and the humidification chamber the problem will not be completely overcome, because the air within the reservoir can still be compressed, and preferably there is therefore provided a reservoir chamber communicating with the humidification chamber by way of a water feed port and a valve for controlling the flow of water through said port, said valve preferably closing during the compression (inspiratory) phase and when the level of water within said chamber rises above a predetermined level but operating to admit water to the humidification chamber while preventing the water level within the humidification chamber from reaching such a level that it interferes with gas passage between the inlet and outlet ports.

The invention will now be described in more detail, by way of example, with reference to the accompanying largely diagrammatic drawings, in which:

Figure 1 is a schematic representation of a humidifier illustrating the general principles underlying the invention;

Figure 2 is a perspective view of a medical humidifier;

Figure 3 is a sectional view of a portion of the humidifier shown in Figure 2; and

Figure 4 is a schematic representation of electrical circuitry associated with the humidifier shown in Figures 2 and 3.

As shown in Figure 1, a gas such as air or oxygen is delivered by way of a conduit 10 to a heated-tank-type humidifier 11 where the gas is warmed and humidified after which it is passed from the humidifier 11 to a delivery point 12, typically a patient, via a flexible delivery line 13. The humidifier 11 is controlled to humidify the gas to a percentage saturation level $W_1$ less than 100% relative humidity and, typically, to a percentage saturation level of 80-90% saturation and to heat the gas to a temperature $T_1$ higher than the temperature $T_2$ required at the delivery point. Then, to provide for delivery of the gas to the patient at a desired higher percentage saturation level $W_2$, typically at 100% saturation, the temperature along the delivery line is controlled to give the lower temperature $T_2$ at the delivery point. The values of $T_1$, $W_1$, $T_2$ and $W_2$ are chosen such that (a) when the gas reaches the delivery point at the desired temperature T2 it has the desired vapour level $W_2$, and (b) that condensation is prevented from forming in the delivery line.

Temperature control is effected in order to partially-offset heat losses along the delivery line and so provide the desired lower temperature $T_2$ by locating a resistance heater 14 within the delivery line.

A medical humidifier for use in the invention is shown in Figures 2 and 3 and forms the subject of my co-pending divisional application 1670/76. (Serial No. 1448474). It comprises a reservoir chamber 15 which is mounted to a humidification chamber 16, the two chambers 15 and 16 being screw connected at 17. It will be noted that the reresvoir chamber 15 and the humidification chamber 16 comprise an integral structure, the reservoir chamber being disposed above the humidification chamber and separated therefrom by a common partition 18 having an aperture 19 which is the water feed port and which connects the humidification chamber 16 with the reservoir 15. A predetermined water level is maintained within the humidification chamber by a float supported needle valve 20 which is located in the humidification chamber inside an enclosure which is spaced at its lower end above the floor of the humidification chamber and which allows unobstructed flow of liquid through it, said enclosure being constituted by a cage portion 21 of the reservoir base. The float 20 can be operated to a closed position in which it seals against the port 19 when the water level in the humidification chamber 16 rises above the predetermined level and when the pressure in the chamber rises, for example during inspiration.

It will be noted that the cage portion 21 defines with an upper portion of the humidification chamber an annular passage which annular passage terminates at its

upper end above the level of the lower end of the water feed port 19 and above a gas inlet port 23 and a gas outlet port 24 whereby, should the water level in the humidification chamber rise to the level of the water feed port, two arcuate flow paths extending along opposite halves of the cross-section of the humidification chamber from the gas inlet port 23 to the gas outlet port 24 still exist above the water level for flow therethrough of gas passing through the humidification chamber from the gas inlet port to the gas outlet port.

An air-tight cap 22 provides an opening for the reservoir which when closed is gas-tight.

Respiratory gas e.g. air (or oxygen) to be heated and humidified is directed into the humidification chamber 16 by way of the inlet port 23, and the heated-humidified gas passes from the humidification chamber by way of the exit port 24 and delivery line 25. Heat transfer to the water within the humidification chamber and to air passing through it is effected by way of a heating coil 26 upon which the humidification chamber 16 normally sits. The heating coil 26 is located within a pocket portion 27 of a casing 28 which houses the control gear associated with the humidifier, with the delivery line 25 and with the temperature sensor at the delivery point end thereof (which control gear is shown in Figure 4 of the drawings).

It will be noted that the water feed port 19 opens into the humidification chamber 16 at a level which is not higher than the level of the inlet port 23 and the exit port 24 and that under normal operating conditions (i.e. when the reservoir is not being filled with water), the reservoir is sealed by means of the air-tight cap 22 whereby the level of water in the evaporation chamber is prevented from rising to a level such that water flows out through the inlet and exit ports of the evaporation chamber or interferes with the passage of gas therethrough in the event of the float 20 sticking in the open position. Also, a fail-safe high/low water sensor device (not shown) is incorporated in the wall of the humidification chamber 16.

The delivery line 25 is constituted by a flexible plastics hose which has a helical electrical resistance element (14, see Figure 1) embedded in its wall. The resistance element functions as a secondary heater, as above described with reference to Figure 1. The delivery line 25 is connected between the exit port 24 and the delivery point which is an endotracheal tube connector 29 to which the delivery line is joined by a coupling 30 fitted within its interior with a sensor 31, such as a thermistor or platinum resistance element, wired to the control gear. The sensor serves to detect the temperature level of gas passing from the delivery line and control the electrical energy, supplied to the resistance element 14.

The control gear associated with the above described apparatus is shown in Figure 4 and includes a power supply 32 (which may be a mains supply). The power supply is connected through a variable or manually pre-settable temperature controller 33 to the gas/water heater 26, and through a transformer 34 to a variable temperature controller 35. The temperature controller 35 provides a low voltage energising current to the heater coil 14, the current level being selectively variable to effect a required heat transfer to gas passing through the delivery line 25 such that the gas cools during its passage through the delivery line but condensation is prevented from forming therein. Adjustment of the controller 35 (to provide for current variation) can be effected both manually to preset the heater 14 and automatically, in response to the signal from the sensor 31. A delivery-gas-temperature read-out device 36, which is controlled by the sensor 31, is incorporated in the circuit.

In operation of the device above described, the heater 14 is controlled automatically (as above mentioned) to provide for a desired gas temperature $T_2$ at the delivery end of the line 25. Also, the heating level of the heater coil 26 is adjusted and set to effect heating of the gas passing through the humidification chamber 16 to a temperature $T_1$ which will provide for a desired percentage saturation level $W_2$ at the delivery point temperature $T_2$.

Therefore, although the simple type of humidifier described herein would not normally produce full saturation of a gas within the humidification chamber over the whole range flow rates which would be required in medical practice, this is not a problem with the apparatus of the invention. The temperature of the system in accordance with the above described embodiment may be adjusted in such a manner that a controlled temperature drop (i.e., $T_1$—$T_2$) is permitted along the delivery line to produce full saturation at the delivery point. By controlling the temperature drop in such a manner that full saturation does not occur before the delivery point, condensation is prevented from occurring within the delivery line.

A further significant feature of the device above described is that the reservoir cap 22 may be removed to permit replenishment of the reservoir 15 without there being a need to disconnect the device from a patient circuit.

WHAT I CLAIM IS:—

1. Apparatus for delivering humidified gas at a desired temperature to a delivery point comprising:

a humidification chamber for supplying warm humidified gas and having an inlet port for gas to be humidified and an outlet port for the warm humidified gas;

a delivery line between the outlet of the humidification chamber and the delivery point;

a temperature sensor at the delivery point end of the delivery line for providing a signal significant of the delivered gas temperature; and

heating means for preventing condensation from forming in the delivery line and for maintaining the temperature of the gas supplied to the delivery point at the desired value, and including an electrical resistance heater provided along the delivery line and whose heat dissipation is controlled independently of the temperature of humidifying liquid in the humidification chamber by means of a first temperature controller responsive to the signal from the temperature sensor.

2. An apparatus according to claim 1, further comprising a reservoir chamber communicating with the humidification chamber by way of a water feed port and a valve to admit liquid to the humidification chamber from the reservoir chamber but to prevent liquid within the humidification chamber from reaching such a level that it interferes with gas passage between the inlet and outlet ports.

3. An apparatus according to claim 2, wherein the water feed port opens into the humidification chamber at a level which is not higher than the gas inlet and outlet ports, and under normal operating conditions (as defined herein) the reservoir is sealed, whereby the level of water in the humidification chamber is prevented from rising to a level such that the water flows out through the gas inlet and outlet ports or water interferes with the passage of gas therethrough in the event of the valve sticking in the open position.

4. An apparatus according to claim 2 or 3 wherein the valve is operated by a float within the humidification chamber and wherein the valve is operated to a closed position when the pressure within the humidification chamber rises and when the level of water within said chamber rises above a predetermined level.

5. An apparatus according to claim 2, 3 or 4, wherein the reservoir is provided with an opening for admission of water said opening having a removable air-tight closure.

6. An apparatus according to any one of claim 4 or 5, wherein the float is located in the humidification chamber inside an enclosure which is spaced at its lower end above the floor of the humidification chamber and which allows unobstructed flow of liquid through it.

7. An apparatus according to claim 6, wherein the enclosure defines with the upper portion of the humidification chamber an annular passage which passage terminates at its upper end above the level of the lower end of the water feed port and the gas inlet and outlet ports whereby, should the water level in the humidification chamber rise to the level of the lower end of the water feed port, two arcuate flow paths extending along opposite halves of the cross section of the humidification chamber from the gas inlet port to the gas outlet port still exist above the water level for flow therethrough of gas passing through the humidification chamber from the gas inlet port to the gas outlet port.

8. An apparatus according any one of claims 2 to 7, wherein the reservoir chamber and the humidification chamber comprise an integral structure, the reservoir chamber being disposed above the humidification chamber and separated therefrom by a common partition having an aperture which is the water feed port.

9. An apparatus according to any one of the preceding claims, further comprising a heater for the humidification chamber which in operation is positioned thereon, the heat dissipation of the heater being controlled by means of a second temperature controller associated therewith, and said heater being located within a pocket portion of a casing containing the first and second temperature controllers.

10. An apparatus according to any one of the preceding claims, wherein the delivery line is a tube of flexible plastics material and the electrical resistance heater is disposed within or about the wall of the tube and extends substantially the whole length thereof.

11. An apparatus according to any one of the preceding claims, further comprising a delivery-gas temperature read-out device controlled by the temperature sensor.

12. An apparatus according to any one of the preceding claims, wherein the first temperature controller operates to cause the gas to cool during its passage through the delivery line but to prevent condensation from forming therein.

13. An apparatus according to claim 1 substantially as herein before described with reference to Figures 2, 3 and 4 of the accompanying drawings.

14. A method for delivery of warm humidified gas to a delivery point, comprising:

heating the gas to a temperature $T_1$ and

to a percentage saturation level $W_1$ of less than 100% saturation;

transferring the gas to a delivery point via a delivery line, sensing the temperature of the gas at the delivery point end of the delivery line by means of a sensor and controlling the temperature of the gas in the delivery line in accordance with signals from said sensor to prevent condensation from forming in the delivery line and to provide for a lower temperature $T_2$ which corresponds with a selected higher percentage saturation level $W_2$ at the delivery point.

15. A method according to claim 14 substantially as hereinbefore described.

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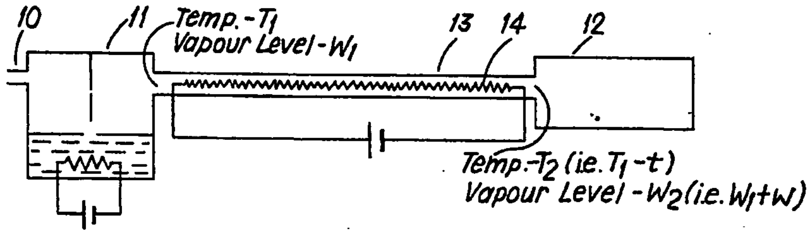
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11
Temp.-$T_1$
Vapour Level-$W_1$
13
14
12
Temp.-$T_2$ (ie. $T_1$-t)
Vapour Level-$W_2$(ie. $W_1$+w)

Fig. 1.

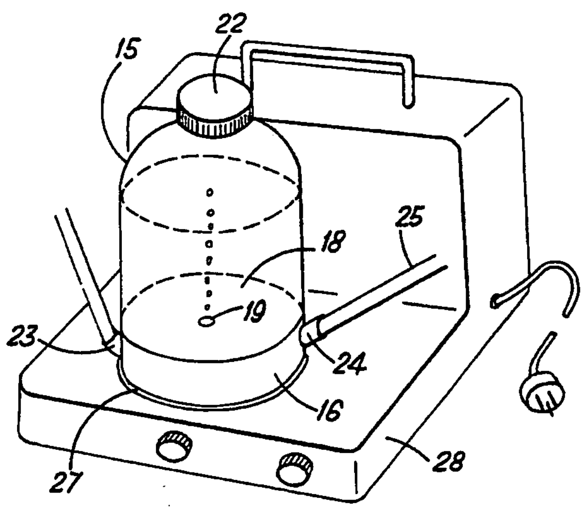
22
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Fig. 2.

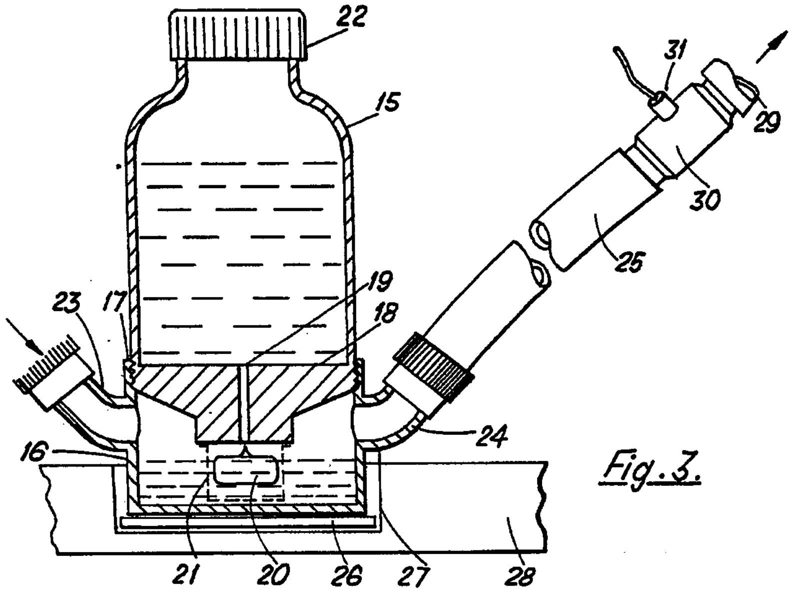
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Fig. 3.

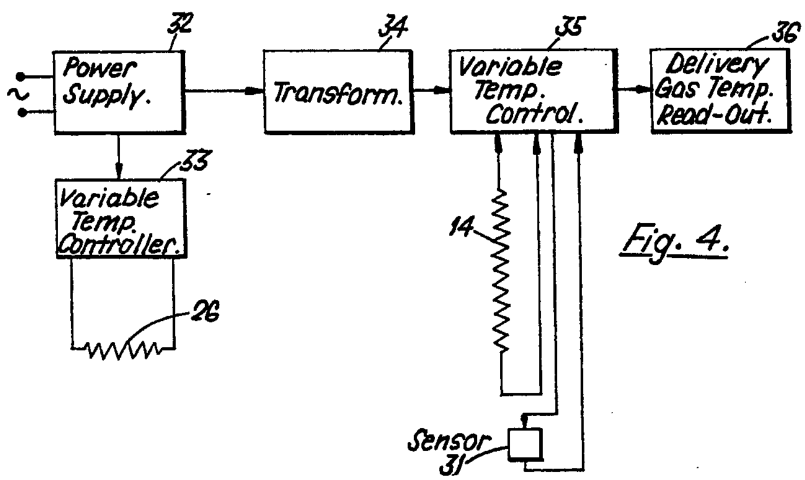
32
Power Supply.
34
Transform.
35
Variable Temp. Control.
36
Delivery Gas Temp. Read-Out.
33
Variable Temp. Controller.
26
14
Sensor 31

Fig. 4.